

## Weather Note

## OCCURRENCE OF SUPERNUMERARY FOGBOWS AT SUBFREEZING TEMPERATURES

RODGER A. BROWN<sup>1</sup>

Department of the Geophysical Sciences, University of Chicago, Chicago, Ill.

In December 1958, at the end of a year-long stay at Little America V, Antarctica, I observed a phenomenon which apparently is quite rare—namely, a fogbow with three supernumerary bows. The following account is based on notes from a meteorological journal that I kept at that time.

A schematic drawing of the fogbows is shown in figure 1. The center of the bows is in the direction of the anti-solar point. The primary bow was a broad, bright band of white a few degrees wide; occasionally a slight suggestion of color was noticed. The lower supernumerary bows (I, II, and III) were fainter and narrower, fluctuating in intensity as the density of the fog changed. Supernumerary III was so faint that its existence could be questioned, but both fellow observer Donald L. Willson and I noted sufficient visual evidence to substantiate its existence.

Supernumerary fogbows were observed from 0800 to 1400 GCT on December 1, 1958 and again at 1400 GCT on the following day (78.2° S., 162.5° W.). During both periods of observation, the temperature was between  $-1^{\circ}$  and  $+13^{\circ}$  F., relative humidity was 85 to 90 percent, wind S to SSE at about 5 m.p.h., visibility was restricted to about  $\frac{1}{4}$  of a mile by fog which obscured 30 to 60 percent of the sky, and the only cloud cover was in the form of thin, scattered cirrostratus.

TABLE 1.—Radii measurements (degrees from antisolar point) of fogbows and their supernumerary bows (I, II, and III)

Date	Time (GMT)	Primary (deg.)	I (deg.)	II (deg.)	III (deg.)
Dec. 1, 1958	1200	38	31	24	17
	1400	36	29	22	(<16)
Dec. 2, 1958	1400	38	31	23	(<16)
Mean		37-38	30-31	23	

At 1200 and 1400 GMT on December 1 and 1400 on December 2, I used a clinometer to measure the elevation of the sun (14, 16, and 16 deg., respectively) and the elevation of the top of each of the bows. The random errors in measurements should have been no more than 1 deg. The resulting radii of the bows from the antisolar point are presented in table 1. It appears that the sun was too high in the sky at the time of the 1400 observations for the smallest supernumerary to be visible. It is interesting to note that there appears to be an interval of about 7 deg. between each of the bows, with the primary bow being approximately 37 to 38 deg. in radius.

It is not unusual for fogbows to occur at subfreezing temperatures. Simpson [1] observed a fogbow with a radius of 38 deg. and a smaller bow within it near McMurdo Sound in the Antarctic in 1911. At the times of observa-

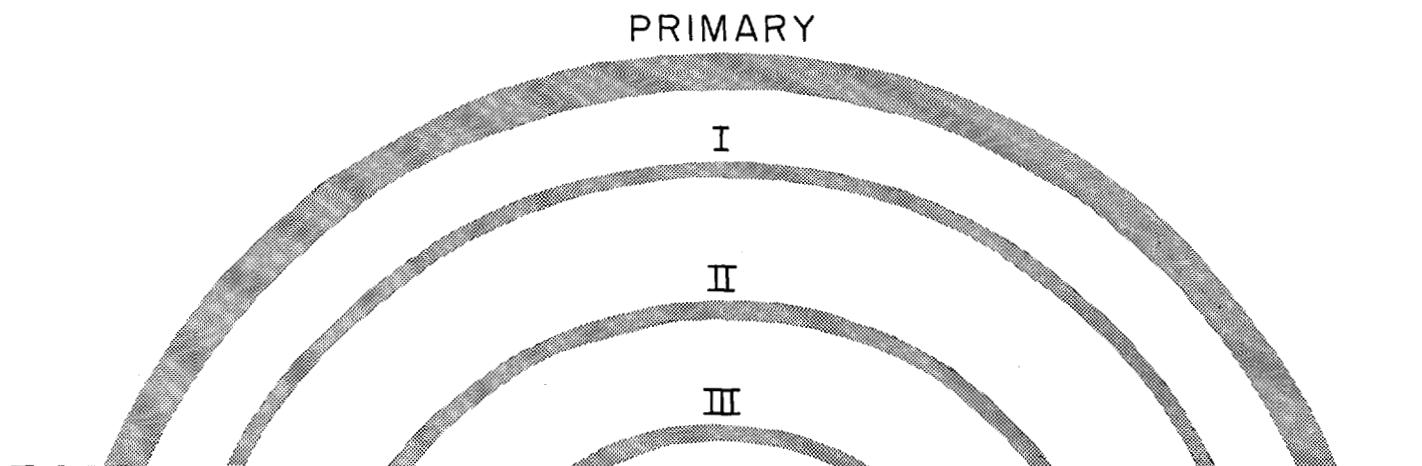
<sup>1</sup> Present affiliation: Cornell Aeronautical Laboratory, Buffalo, New York.

FIGURE 1.—Schematic diagram of the primary fogbow and three supernumerary bows that were observed at 1200 GMT on December 1, 1958, at Little America V, Antarctica.

tion the surface temperature was between  $-15^{\circ}$  and  $-21^{\circ}$  F. He concluded that fog droplets were still liquid at such low temperatures—a fact which was not widely accepted at that time—since hoar frost formed on their garments. He further cited the theoretical work of Pernter [2] which predicts that droplets with a radius of  $25\mu$  produce a broad white bow with yellow outer and violet inner edges; the total extent is from 37 to 41 deg. of radius. Also a secondary bow should appear at a radius of about 35 deg. Consequently Simpson concluded that the fogbow he saw was composed of supercooled water droplets with radii smaller than  $25\mu$ , since both the radius and the coloring of a bow decreases with decreasing droplet size. (Apparently the same is true for the above observations since the maximum radius of the primary bow was only 38 deg.)

Subsequent observations have left no doubt that fogbows can be caused by supercooled water droplets (see, e.g., Brooks [3]). During the Norwegian-British-Swedish Antarctic Expedition of 1949–52, Liljequist [4] observed liquid-water fogbows at temperatures as low as  $-18^{\circ}$  F.; the one measurement that he made of a fogbow revealed a mean radius of 37.5 deg.

A cursory check of literature on meteorological optics revealed no references to radii measurements of super-

numerary bows. In fact, the only mention that I could find of more than one supernumerary bow stated that within the primary bow, “with a space between them, one or even two supernumerary bows are to be seen” [5].

Therefore, it appears that the second supernumerary is rarely observed and that the existence of the third one is virtually unknown; this latter fact is most likely due to the requirement that the elevation angle of the sun has to be less than 16 deg. before the bow can be seen. The measurements cited above should prove to be valuable in confirming theoretical studies of supernumerary fogbows caused by droplets with radii less than  $25\mu$ .

#### REFERENCES

1. G. C. Simpson, “Coronae and Iridescent Clouds,” *Quarterly Journal of the Royal Meteorological Society*, vol. 38, No. 164, Oct. 1912, pp. 291–301.
2. J. M. Pernter, *Meteorologische Optik*, W. Braumüller, Vienna, vol. 3, 1910, p. 247.
3. C. F. Brooks, “Coronas and Iridescent Clouds,” *Monthly Weather Review*, vol. 53, No. 2, Feb. 1925, pp. 49–58.
4. G. H. Liljequist, “Halo-Phenomena and Ice-Crystals (Maudheim,  $71^{\circ}03'$  S.,  $10^{\circ}56'$  W.),” *Norwegian-British-Swedish Antarctic Expedition, 1949–52, Scientific Results*, Norsk Polar-institutt, Oslo, vol. 2, Part 2, 1956, pp. 55–57.
5. M. Minnaert, *The Nature of Light and Color in the Open Air*, Dover Publications, Inc., New York, 1954, p. 183.

## CORRESPONDENCE

### Comments on “Weather Note: Rapid Intensification of Hurricane Cleo, August 1964”

DONALD ROSENFELD

Massachusetts Institute of Technology, Cambridge, Mass.

It is not exactly clear what Mr. Kraft [1] is suggesting in his recent note, but if he is saying that forecasters could predict intensification of tropical cyclones beforehand by the degree of angle associated with spiral bands I would be inclined to disagree. I feel that intensification occurs before the change in angle of spiral band curvature. This change of curvature, I believe, is caused by the increase of low-level inflow becoming more ageostrophic as the cyclone increases in intensity. This assumes that the basic inflow-outflow model is correct; i.e., intensity is primarily based on an increase in the outflow at very high

levels resulting in an increase of inflow at low levels.

If a definite correlation can be found for curvature vs. storm intensity, the degree of curvature should prove useful as a research tool following the storm or during a time when a vortex is under radar observation only and intensity information is needed.

#### REFERENCE

1. R. H. Kraft, “Weather Note: Rapid Intensification of Hurricane Cleo, August 1964,” *Monthly Weather Review*, vol. 93, No. 7, July 1965, p. 444.